Research on the Coupling and Coordination of Land Ecological Security and Economic Development Level

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Abstract

Land ecological security is the degree of guarantee for the health and stability of land resources. As the level of economic development rises, the process of infrastructure construction and urbanization accelerates. Analyzing the coupling and coordination of the two reflects the scale or level of socio-economic phenomena in different periods and provides a scientific basis and decision-making support for the rational use of land resources and the protection of the ecological environment.

Keywords

Land ecological security, economic development, coupled coordination analysis.

1. Introduction

The level of land ecological security refers to the ability of a land ecosystem to maintain its structural, functional, and material circulation stability within a certain time and space range.[1] It is able to maintain the normal operation of biodiversity, ecological processes, and ecological services, as well as to have a certain resistance and recovery ability to natural and human disturbances. The level of land ecological security reflects the health status and sustainable development ability of the land ecosystem.[2]

The level of economic development refers to the extent and degree of the economic total, economic structure, economic efficiency, and people's living standards in a country, region, or organization over a certain period.[5] It is usually measured by indicators such as the total national economic volume, per capita gross domestic product (GDP), per capita income, consumption level, trade activities, and technological level. The level of economic development reflects a country's or region's economic strength, productivity level, social welfare, and international competitiveness.

The close relationship between land ecological security and economic development is evident.[15]Studying the coupling relationship between the two can optimize resource allocation, improve resource utilization efficiency, and achieve a win-win situation for both economic and ecological benefits. Economic development may have certain impacts on the land ecological environment.[17] Research on coupling relationships can effectively protect the land ecological environment and maintain the stability and healthy development of ecosystems.[18] Furthermore, the coupling and coordination between the level of land ecological security and economic development are crucial for promoting sustainable development, formulating policies, ensuring national security, and enhancing people's well-being.[20]

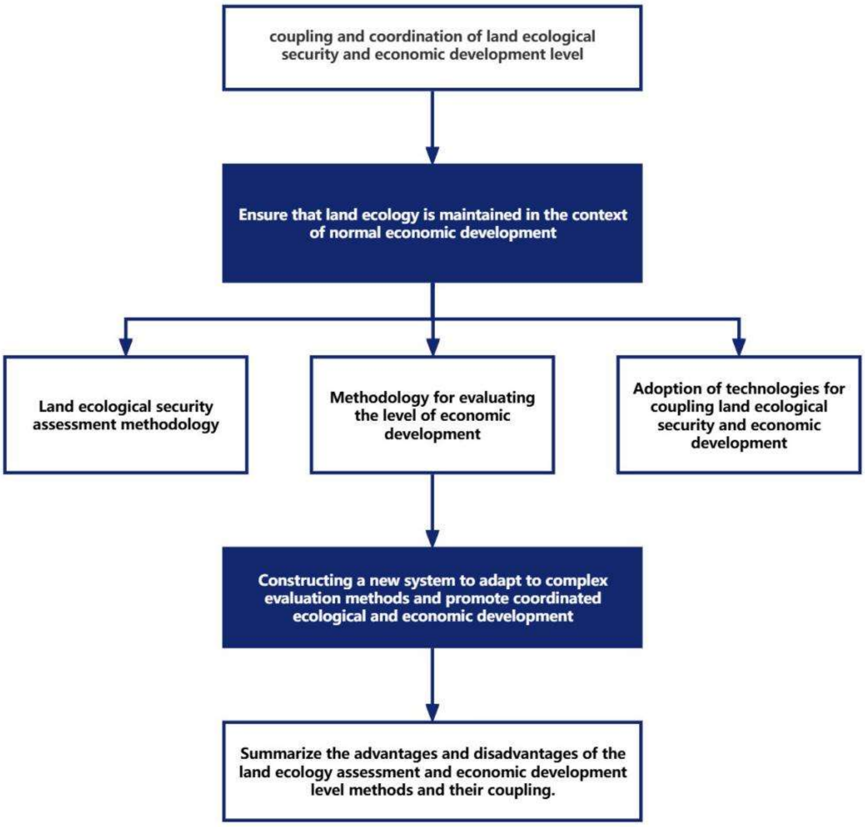

Figure 1. Article content architecture

2. Land Ecological Security Assessment Methodology

2.1. Comparison of Evaluation Methods

Currently, domestic and foreign scholars have conducted numerous studies on methods for evaluating land ecological security, leading to the development of a more mature evaluation system and the establishment of a comprehensive evaluation methodology.[6] Examples of such methods include the polarization method, entropy weight method, ideal point ranking method, and factor obstacle degree model.[8]

The polarization method is employed to polarize the raw data, thereby mitigating the issue of dimensionlessness. Yang Diem-Chen et al. utilized the polarization method to preprocess raw data, ensuring the meaningfulness of logarithmic operations when analyzing the entropy values of various data sets related to land ecological security.[9]

(1) Standardization of positive indicators

$$P= t \cdot \left(\frac{x - \min(x)}{\max(x) - \min(x)} \right) (+q)$$

Standardization of negative indicators

$$P= t \cdot \left(\frac{\max(x) - x}{\max(x) - \min(x)} \right) (+q)$$

In different articles, the formula for extreme value processing may vary.[16] For example, the uncertainty of the constant term in the calculation of extreme value processing for positive and negative indicators is used to adjust the result range, eliminate the negative value impact, and facilitate comparison and weighted calculation. The value may be set to 0.01, but the specific value can be adjusted according to needs to meet specific evaluation standards and requirements. The range method typically involves converting raw data into range values for comparison or weighting purposes. In contrast, the entropy weight method involves converting data into entropy values to reflect their relative importance. The entropy method aims to determine the information entropy of various data related to land evaluation and safety.[4] A smaller entropy indicates less disorder, greater actual utility, and higher weight. Li Bing et al. applied the entropy method to assign values to indicators, reducing the degree of human interference compared to subjective assignment methods.[13]

(1) Calculation of the weight of the indicator value of indicator a in year P

$$P = \frac{S_{ab}}{\sum_{i=x}^{n} S_{ab}}$$

(2) Calculate the entropy value E

$$E_{\mathrm{a}} = -\frac{1}{\mathrm{lnm}} \sum_{i=x}^{n} \left(P_{ab} \cdot \ln P_{ab} \right)$$

(3) Calculate the weights W

$$W = \frac{1 - E}{K - \sum_{a=1}^{n} E_a}$$

At the end of the 20th century and the beginning of the 21st century, with the increasingly prominent issue of land security, researchers began to introduce the entropy method into land security evaluation.[22] In recent years, with the deepening of research, the application of the entropy method in land security evaluation has gradually been improved and developed. The entropy method is often combined with other evaluation methods, such as the Analytic Hierarchy Process (AHP), grey system theory, and fuzzy comprehensive evaluation method, to form a multi-method comprehensive evaluation system, in order to improve the reliability and accuracy of the evaluation results. At the same time, by introducing time series data, dynamic evaluation is conducted to reflect the temporal change characteristics of land security conditions.

The weights are determined by calculating the distance from each criterion to the ideal and negative ideal solutions in the ideal point ranking method, while the optimal solution is determined by calculating the distance from each scheme to the ideal and negative ideal solutions. In contrast, in the entropy weight method, weights are calculated based on the entropy value of the data, where a larger entropy value corresponds to a smaller weight, and the optimal solution is determined by calculating the comprehensive evaluation value of each scheme. The ideal solution ranking method aims to optimize each attribute value to either the best or worst among alternatives. Liu Shaokun et al. constructed an evaluation index system to derive the optimal method (positive ideal solution) and the worst solution (negative ideal solution). They then calculated the Euclidean distance and relative proximity.[19]

(1) Weighted normalization matrix

$$V_{\mathrm{ij}} = (Y_{ij} \times W_j)_{m \times n}$$

(2) positive ideal solution

$$P^{+} = \max V_{i1}, \max V_{i2} \ldots\ldots \max V_{in}$$

negative ideal solution

$$P^{-} = m\mathrm{in} V_{i1}, \min V_{i2} \ldots\ldots \min V_{in}$$

(3) Distance between the actual level of the evaluation unit and the positive ideal solution

$$D^{+} = \sqrt{\sum_{j=1}^{\mathrm{n}} \left(V_{ij} - V^{+}\right)^{2}}$$

Distance between the actual level of the evaluation unit and the negative ideal solution

$$D^{-} = \sqrt{\sum_{j=1}^{\mathrm{n}} \left(V_{ij} - V^{-}\right)^{2}}$$

(4) Land Ecological Security Index

$$U_{\mathrm{i}} = \frac{D^{-}}{D^{-} + D^{+}}$$

This is just one scenario in the Ideal Point Method, which has subtle differences in land evaluation methods. This is mainly due to differences in evaluation objects, as well as differences in evaluation purposes and focuses. For example, under the diversity of evaluation objects, different types of land have different evaluation indicators and weights. Similarly, differences in evaluation purposes and focuses will also lead to differences in results due to different needs.Multiple factors influencing outcomes are considered in both the Ideal Point Ranking Method and the Factor Obstacle Model. The Factor Obstacle Model considers multiple factors affecting people's behavior and choices, while the Ideal Point Ranking Method considers the impact of multiple criteria on solutions.The factor obstacle degree model calculates the obstacle degree of each evaluation indicator in the comprehensive evaluation. It identifies the key factors that restrict further development and clarifies the factors that significantly impact evaluation results. This model also clarifies the degree of influence of key constraints, providing

a scientific basis for formulating policies. Guo Dongyan et al. calculated the size of obstacles at the level of evaluation indicators and guidelines to determine their impact on the objectives.[21]
(1) Deviation of evaluation indicators

$$S_{ij} = 1 - Y_{ij}$$

(2) Degree of obstacles at the indicator level

$$M_{ij} = S_{ij} W_{ij} \times \frac{100\%}{\sum_{j=1}^{n} S_{ij} W_{ij}}$$

3. Methodology for Evaluating the Level of Economic Development

3.1. Comparison of Evaluation Methods

Both economic development levels and land ecological security assessments are complex and systematic issues that require the comprehensive consideration of multiple factors and indicators.[3] Therefore, when facing such problems, including the consideration of multiple indicators, comprehensive analysis, scientific objectivity, and operational characteristics, has led to some similarities in methodology between them.The method for evaluating the level of economic development is similar to that used for assessing land ecological security. It involves calculating a comprehensive index of high-quality economic development using the polarization method, the entropy weight method, the ideal point ranking method, and the factor barrier degree model.[7]
Determination of the system of evaluation indicators
(1) polarization method
Standardization of positive indicators

$$P= t \cdot \left(\frac{x - \min(x)}{\max(x) - \min(x)} \right) (+q)$$

Standardization of negative indicators

$$P= t \cdot \left(\frac{\max(x) - x}{\max(x) - \min(x)} \right) (+q)$$

(2) Entropy weight method

$$F_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}}$$

$$E_j = -\frac{1}{\ln m}\sum_{i=1}^{m} F_{ij}\ln\left(F_{ij}\right), 0 \le E_j \le 1$$

$$W_j = \frac{\left(1 - E_j\right)}{\sum_{i=1}^{n}\left(1 - E_j\right)}$$

(3) Ideal point ordering method

$$V_{\mathrm{ij}} = \left(Y_{ij} \times W_j\right)_{m \times n}$$

$$P^{+} = \max V_{i1}, \max V_{i2} \ldots\ldots \max V_{in}$$

$$P^{-} = \min V_{i1}, \min V_{i2} \ldots\ldots \min V_{in}$$

$$D^{+} = \sqrt{\sum_{j=1}^{\mathrm{n}}\left(V_{ij} - V^{+}\right)^2}$$

$$D^{-} = \sqrt{\sum_{j=1}^{\mathrm{n}}\left(V_{ij} - V^{-}\right)^2}$$

(4) Factor Barrier Degree Model

$$S_{ij} = 1 - Y_{ij}$$

$$M_{ij} = \frac{S_{ij} W_j \times 100\%}{\sum_{j=1}^{n} S_{ij} W_j}$$

$$I = \sum M_{ij}$$

4. Adoption of Technologies for Coupling Land Ecological Security and Economic Development

4.1. Comparison of Different Evaluation Models

Land ecological security and economic development belong to two independent systems, each comprising many elements, forming a complex system. Scholars at home and abroad have proposed different models, such as the PVAR model, grey correlation model, coupling coordination model, and others, to solve this research problem.[23]

The PVAR model overcomes problems of endogeneity by combining the advantages of panel data and the VAR model. The development of the PVAR model began in the late 1980s and early 1990s, with the advancement of econometrics and time series analysis methods. The PVAR model has been widely used to study dynamic relationships and influencing factors in panel data. In recent years, nonlinear models and heteroskedastic adjustments have been introduced to improve the model's goodness of fit and explanatory power. Guo Dongyan et al. constructed a PVAR model to analyze the causal relationship between variables and predict the effects of shocks between random disturbances and variables.[21]

$$Y_{it} = \alpha_{it} + f_t + \sum_{t-1}^{n} \Pi_{nt} Y_{i,t-n} + \mu_{it}$$
$$Y_{it} = \{LES, HED\}$$

Both the P-AVR model and the Grey Relational Analysis model consider the influence of multiple factors on the evaluation results, making the evaluation more comprehensive and accurate. In the evaluation process, both models require a comprehensive analysis of multiple aspects to fully understand the situation of the evaluation object. They emphasize scientific and objectivity by supporting evaluation results with data and indicators to reduce the impact of subjective factors.The grey correlation model serves as a measure of the correlation level between factors, based on the degree of similarity or dissimilarity in trends among them. Yang Diem-Chen et al.measured the correlation level between the parent series and the characteristic series statistics. They used this measure to assist in decision-making analysis by correlating the statistics according to the degree of correlation level.

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$$\zeta_i(k) = \frac{\min(i)\min(k)\left|y(k) - x_i(k)\right| + p\max(i)\max(k)\left|y(k) - x_i(k)\right|}{\left|y(k) - x_i(k)\right| + p\max(i)\max(k)\left|y(k) - x_i(k)\right|} \quad r_i = \frac{1}{n}\sum_{k=1}^{n} \zeta_i(k)$$

The grey relational analysis model can reveal the relationship between land ecological security and economic development levels, assess influencing factors, predict development trends, and optimize decision-making, providing support for the sustainable utilization of land resources and the sustainable development of the economy and society.

The coupling coordination model is primarily used to assess the degree of coordination among internal factors of a system, as well as the overall coordination of the system; whereas the grey relational model is mainly used to evaluate the degree of correlation among internal factors of a system, and the extent to which these factors influence the overall system. The coupled coordination degree model is used to analyze the level of coordinated development among various factors. Li Nan et al. utilized the coupling coordination degree to understand the dynamic correlation relationship between land ecological security and the level of economic development, reflecting the degree of dependence and constraint between these two systems.

$$C = \left\{AB / \left[(A + B)/2\right]^2\right\}^2$$
$$T = \alpha A + \beta B$$
$$D = \sqrt{CT}$$

This coupling coordination model is just one of many.[10]It is a comprehensive choice made in this article based on the specific situation. Different articles on the coupling coordination between land ecological security and economic development levels use different coupling coordination models, which is due to differences in research objects, research methods, research hypotheses, data availability, and research purposes.[11] However, it is generally recognized that coupling coordination models are of great significance for studying land ecological security and economic development levels.[14]

4.2. Comprehensive Analysis and Summary

The methods for evaluating land ecological security and economic development levels differ, each with their own advantages and disadvantages, and their coupling studies highlight these differences.[12] The range method, entropy method, TOPSIS, and obstacle degree model each have their strengths and weaknesses: the range method is simple and intuitive but easily affected by extreme values; the entropy method objectively allocates weights but is computationally complex; TOPSIS considers multiple dimensions but is highly sensitive; the obstacle degree model can identify major barrier factors but depends on data quality.[24] Similarly, the PVAR model, grey correlation model, and coupling coordination model each have strengths and weaknesses in studying the coupling between land ecological security and economic development. The PVAR model is suitable for dynamic data but has high parameter requirements; the grey correlation model handles incomplete information but has limited accuracy; the coupling coordination model intuitively reflects the coupling relationship but may overlook details.[25] Overall, these models vary in processing capabilities, accuracy, and application scenarios, necessitating a choice based on research needs.

4.3. Literature Comment

The methods and models for assessing land ecological security and economic development levels have become relatively mature. Here are some research perspectives and structural suggestions to further enhance the efficiency of studies and the comprehensiveness and reliability of assessment results:Firstly, it is recommended to build an assessment framework that integrates multiple methods such as the interval method, entropy method, TOPSIS, and the obstacle degree model. This integrated framework allows for a comprehensive analysis of land ecological security and economic development levels from various perspectives, thereby improving the credibility of the results. For example, the interval method can handle uncertain data, the entropy method can measure the relative importance of indicators, TOPSIS can perform comprehensive evaluations, and the obstacle degree model can identify key obstacles in the assessment process.Secondly, future research should focus on optimizing data processing techniques. Data quality is the foundation of assessments, so it's crucial to enhance the application of techniques like outlier detection and correction, median substitution, and data interpolation. These techniques can effectively improve the accuracy and completeness of the data, ensuring the reliability of the assessment results.Thirdly, enhancing the dynamic analysis capabilities of the PVAR (Panel Vector Autoregression) model and the coupling coordination model, and simplifying parameter settings, is essential. Incorporating automatic optimization technology can improve the applicability and operational simplicity of the models while maintaining accuracy. This will help better reflect the dynamic relationship between land ecological security and economic development.Fourthly, conducting detailed regional disparity analyses is important. Using the grey relational model and the coupling coordination model for targeted empirical studies can provide scientific basis for local policy-making by exploring the disparities between different regions. For example, the grey relational model can analyze the correlation between ecological security and economic development in different regions, while the coupling coordination model can assess their coordination degree, thus providing targeted policy recommendations.Lastly, research outcomes should be closely aligned with actual policy needs. The findings from different regions should be analyzed specifically to propose actionable policy suggestions, ensuring that the assessment results effectively guide the coordinated advancement of land management and economic development. Additionally, strengthening cooperation between researchers and policymakers is crucial. By utilizing assessment results to inform policy-making, the integration of research and practice can be achieved.By following these suggestions, the scientific and practical aspects of assessing land ecological security and economic development levels can be further enhanced, promoting the coordinated development of land management and economic growth.

5. Summary

In this comprehensive review article on the coupling coordination study of land ecological security and economic development, various scholars exhibit divergent viewpoints and approaches in their research and application of the same methods and models, contingent upon specific contextual preferences such as simplicity and comprehensiveness. For instance, regarding outlier handling, there exist two primary strategies: deletion or substitution. Wang, L., & Zhang, J., in their study "Research on Coupling Coordination Between Land Ecological Security and Economic Development in China," utilized the interquartile range (IQR) method to identify and delete extreme data points exceeding 1.5 times the IQR range, subsequently recalculating economic development levels and ecological security indices. Conversely, Li, Y., & Chen, H., in their work "Coupling and Coordination Analysis of Land Ecological Security and Economic Development in the Yangtze River Delta," opted to substitute extreme values caused by temporary policy changes or natural disasters with neighboring year averages to minimize their impact on overall analysis. In "Evaluation of Land Ecological Security and Economic Development Coordination in Northeast China," Sun, J., & Wang, Q. employed the z-score normalization method to transform data into a normal distribution with a mean of 0 and standard deviation of 1, reducing the influence of outliers and facilitating more accurate assessments of the coupling coordination between land ecological security and economic development across different provinces. Regarding data processing, Zhang, T., & Zhao, X., in "Assessing the Coupling Coordination Between Land Ecological Security and Economic Development: A Case Study of the Beijing-Tianjin-Hebei Region," standardized initial data, whereas Liu, H., & Wang, Y., chose to utilize raw data. Diverse approaches are also evident in identifying barriers: Li, X., & Chen, Y., in "Identifying Barriers to the Coordination Between Land Ecological Security and Economic Development in the Pearl River Delta," relied on subjective judgment and expert opinions, whereas Zhang, H., & Wang, J., in "Quantitative Analysis of Barriers to Land Ecological Security and Economic Development Coordination Using Machine Learning," employed objective data analysis with machine learning algorithms to identify and quantify barriers. PVAR modeling also varied in emphasis: Wang, H., & Zhang, L., in "Dynamic Coupling of Land Ecological Security and Economic Development Using PVAR Model: A Case Study of the Yangtze River Delta," focused on dynamic parameter selection and setup, whereas Chen, X., & Liu, Y., in "Assessing the Long-term Relationship Between Land Ecological Security and Economic Development Using PVAR Model," emphasized data stationarity and cointegration handling. There are distinctions in coupling coordination models as well: Liu, H., & Zhang, Y., in "Linear Coupling Analysis of Land Ecological Security and Economic Development: A Simplified Approach," utilized traditional linear coupling methods through constructing simple linear regression models to analyze the relationship between land ecological security and economic development, whereas Chen, X., & Wang, L., in "Nonlinear Coupling and Interaction Effects Between Land Ecological Security and Economic Development," introduced nonlinear functions and complex interaction effects using generalized additive models (GAM) and nonlinear regression models to capture nonlinear relationships and intricate interactions among different variables. These methodologies not only deepen the understanding of the relationship between land resource management and sustainable development but also provide a more scientifically grounded theoretical basis and methodological framework for policy formulation and management decision-making.

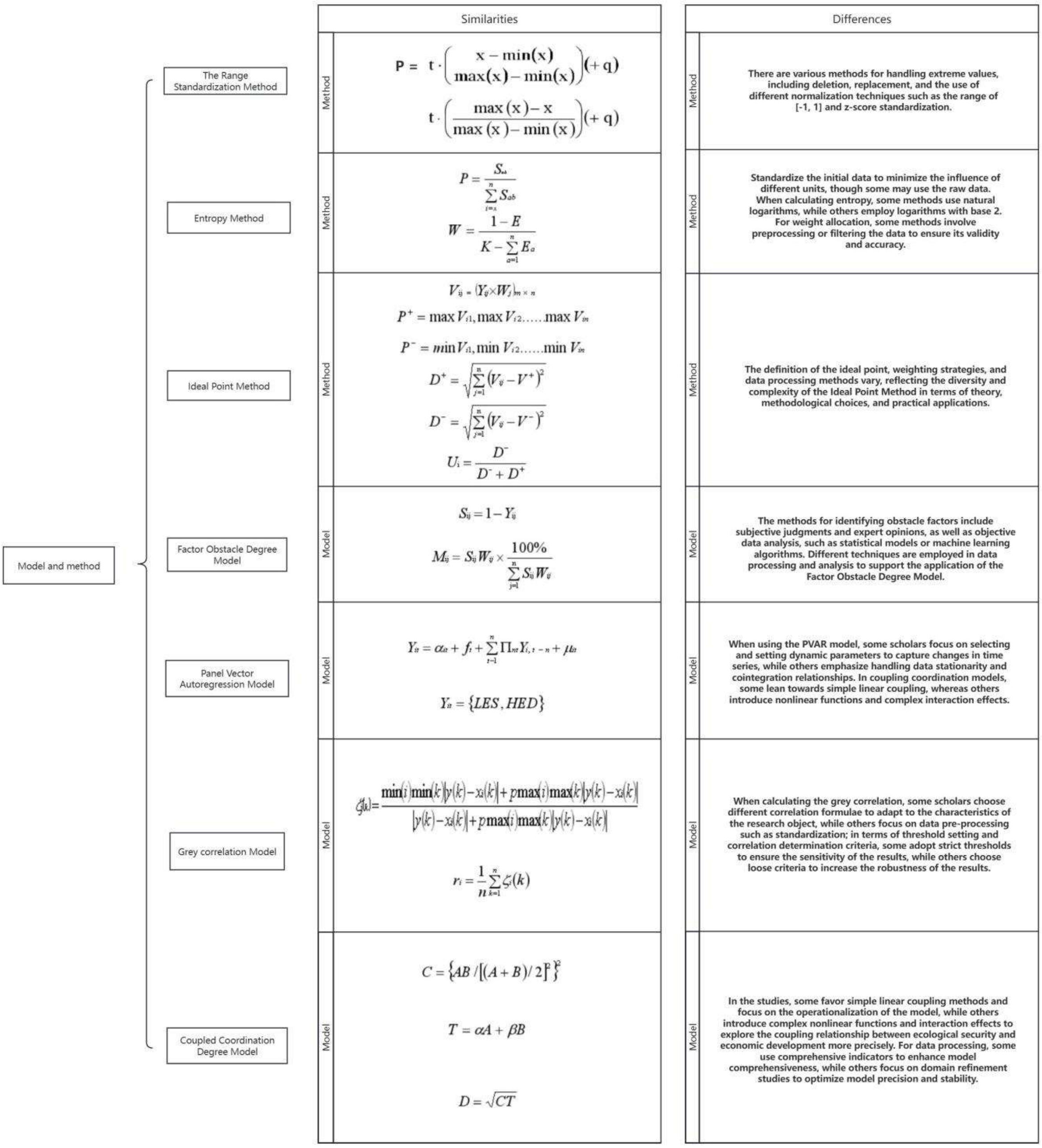

Figure 2. Summary of models and methods

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